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Original communication

Sex identification on the basis of hand and foot measurements in Indo-Mauritian population – A model based approach

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ABSTRACT

Identification is the foremost issue in crime investigation. A few studies have been performed so far in order to identify sex on the basis of single foot or hand of the victim. Moreover, these studies provide only crude measures to indicate sex and there exists no concrete methodology to predict sex using the available information. In the present paper, we have developed statistical models to identify sex based on the dimensions of foot and hand. The models containing both length and breadth of hand or foot as independent variables are capable of predicting sex in Indo-Mauritian population with fairly high accuracy as compared to those containing hand or foot indices.

1. Introduction

Forensic deliberations rest heavily on the identification of an individual involved in a crime. The task becomes extremely challenging when the dismembered and mutilated human remains are the only materials to be used by forensic pathologists for examination. Many studies have been attempted to determine sex by using different body features such as foot shape,[1] foot print ratio,[2] foot and shoe dimensions,[3] the femoral head,[4] the patella,[5] long bones of the arm,[6] and the teeth.[7] Literature search has revealed very few studies[3,8–10] on the determination of sex from foot and hand dimensions.

In the study conducted by Agnihotri et al,[9] it is remarked that in the Indo-Mauritian population, the average hand length as well as breadth for males is about 1 cm greater than for females. On the basis of measurements of hand indices it is concluded that the hand index of more than 44 indicates a male, otherwise a female. In another study by Agnihotri et al,[10] based on the same population, the identification of gender is made using foot measurements. On the average, the male foot is found to be 3 cm longer than the female foot. The foot indices were calculated similar to hand indices, which suggest that the foot index exceeding 37 indicate a female otherwise a male. The hand and foot indices in both the studies[9,10] are in fact crude ratios and serve as primary indicators of sex. Moreover, these studies provide only descriptive measures based conclusions.

According to Moudgil et al,[8] concerning sex detection based on foot measurements among North-Indian population, there are significant differences between male foot length and female foot length as well as corresponding breadths whereas no significant differences are observed between male and female foot index. However, there exists no concrete approach to identify sex. In the present paper, statistical models are developed to predict sex on the basis of hand or foot measurements for the Indo-Mauritian population.

2. Materials and methods

In order to construct the model based predictive equations we use the hand and foot measurements data collected and explored by Agnihotri et al.[9,10] To be specific, the material consisted of 250 young and healthy students (125 males and 125 females) in the age group of 18–30 years. The length and breadth of both hands and feet were measured by using standard anthropometric instruments. Foot length was measured with a rod compass as a straight distance between the most posterior projecting point of heel (pternion) and the most anterior projecting point (the longest toe) when placed on flat surface. Breadth of the foot was measured as

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the straight distance from the most medially placed point on the head of 1st metatarsal to the most laterally placed point located on the head of 5th metatarsal. Hand length was measured with a spreading caliper as the straight distance between distal crease of wrist joint and the most anterior projecting point i.e. tip of middle finger. Breadth of the hand was measured as the straight distance from the most laterally placed point on the head of the 2nd metacarpal to the most medially placed point located on the head of the 5th metacarpal. The indices were calculated for both feet and hands by using the formula: Foot index = (foot breadth/foot length) × 100 and Hand index = (hand breadth/hand length) × 100.

The variables are denoted as follows: RFL (right foot length), RFB (right foot breadth), LFL (left foot length), LFB (left foot breadth), RHL (right hand length), RHB (right hand breadth), LHL (Left hand length), LHB (Left hand breadth), RFI (right foot index), LFI (left foot index), RHI (right hand index) and LHI (left hand index). We intend to identify sex in case only a foot (right or left) or only a hand (right or left) is found. Since it is observed that left limb measurements are different from right limb measurements, prediction equations will be naturally different for left and right limbs. To be specific, if only the right foot is available, the covariates RFL & RFB will be used to construct the model M1. For the same foot, another comparable model M5 can be developed using the right foot index RFI. In the same way models M2 and M6 will be constructed for the left foot, M3 and M7 for the right hand and M4 and M8 for the left hand. Since sex is a binary response variable and the covariates RFL, LFL, RHL, RHB, LHL, LHB follow non-normal distribution (p-value < 0.05 for Anderson–Darling test) as shown in Fig. 1. We propose to develop logistic models for these data. Logistic models are widely applied to study the effects of various explanatory variables on the binary response variable since the simple linear regression models are not appropriate for categorical response data. The pioneer works of Hosmer and Lemeshow[11] as well as that of Agresti[12] provide a complete account of logistics models and their applications.

3. General model equation

The multiple logistic model may be specified as:

$$E(Y) = \left[1 + e^{-X\beta}\right]^{-1}$$

where $E(Y)$ is the mean response for sex, such that $Y = \begin{cases} 1 & \textit{for male} \\ 0 & \textit{for female} \end{cases}$, and β is the p-dimensional vector of parameters associated with the $n \times p$ matrix X of covariates. If π is the probability of identifying a male then the log it response function can be given by

$$\log_e\left(\frac{\pi}{1-\pi}\right) = X\beta.$$

The maximum likelihood estimates (MLE) of the parameters $\beta_1, \beta_2, \ldots, \beta_p$ are obtained iteratively using the method of re-weighted least squares. Note that MLE's are the most efficient estimates. The theory underlying this sophisticated estimation process seems to be complicated but it is quite easy to obtain these estimates using the 'logistic regression' option in any statistical software. We have used the software 'Minitab 16' to analyze our models. The magnitude of the $\hat{\beta}_j$ and the corresponding odds-ratio measures the relative importance of the regressor X_j $(j = 1,\ldots, p)$.

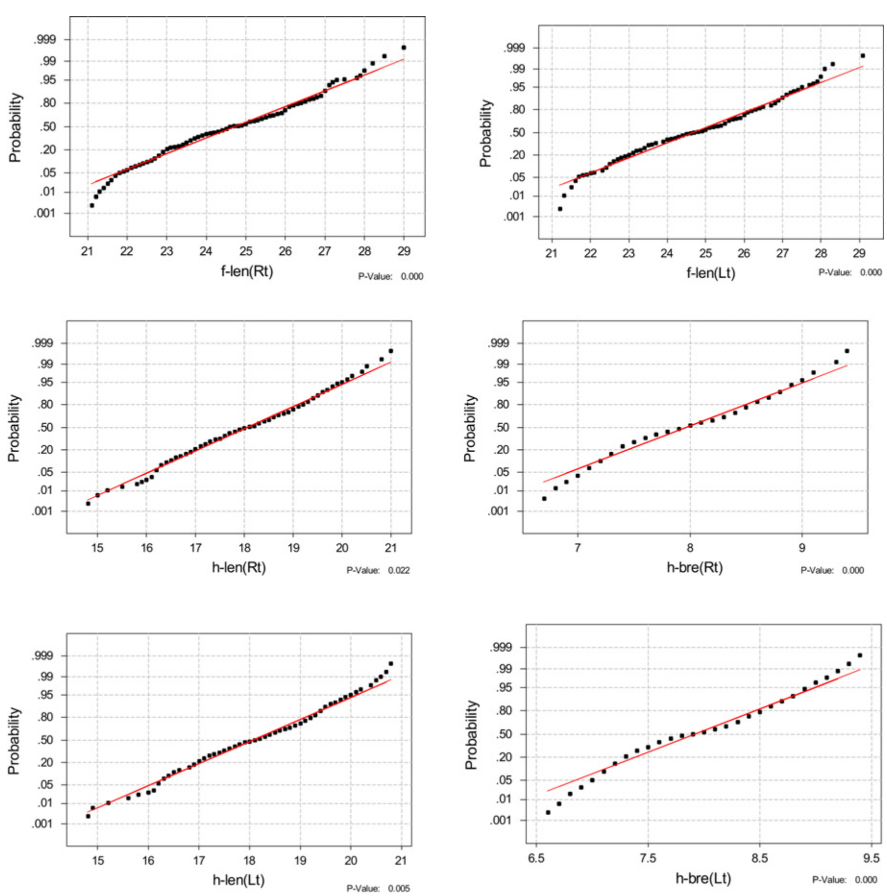

Fig. 1. Normal Probability Plots.

Table 1
Estimation and testing of β.

Model	Covariates	VIF	$\hat{\beta}$	Wald χ^2	p-value	Odds Ratio
M1	RFL RFB	< 2.5	1.93 1.04	41.46 3.50	0.00 0.04	6.89 2.83
M2	LFL LFB	< 2.5	1.97 0.64	39.89 1.16	0.00 0.04	7.17 1.90
M3	RHL RHB	< 3.0	0.65 4.53	4.15 34.89	0.03 0.00	1.92 92.76
M4	LHL LHB	< 3.0	0.66 4.48	4.41 38.16	0.03 0.00	1.93 88.23
M5	RFI	-	−0.16	5.31	0.02	0.85
M6	LFI	-	−0.20	7.15	0.01	0.82
M7	RHI	-	0.38	23.27	0.00	1.46
M8	LHI	–	0.41	27.64	0.00	1.51

Table 3
Fitted model equations.

Model	Fitted Equation
M1	$[1+\exp(57.31-1.93*RFL-1.04*RFB)]^{-1}$
M2	$[1+\exp(54.41-1.97*LFL-0.64*LFB)]^{-1}$
M3	$[1+\exp(47.91-0.66*RHL-4.53*RHB)]^{-1}$
M4	$[1+\exp(47.42-0.66*LHL-4.48*LHB)]^{-1}$
M5	$[1+\exp(-6.07+0.16*RFI)]^{-1}$
M6	$[1+\exp(-7.37+0.20*LFI)]^{-1}$
M7	$[1+\exp(16.62-0.38*RHI)]^{-1}$
M8	$[1+\exp(17.91-0.41*LHI)]^{-1}$

The variance inflation factor (VIF) is an important diagnostic and its value of 10 or more indicates that regressors are correlated and that model is not good. The significance of each regressor is assessed by the Wald test and its p-value. Hosmer–Lemeshow and $-2 \log L$ test-statistics are used to test the utility of the logistic models. Various indicator values such as R^2 and the percentages representing sensitivity and specificity of the models are used to compare the models in order to select the best fitting model.

4. Results and discussion

In our case, for the models M1, M2, M3 and M4: $n = 250$; $p = 2$ and for the models M5, M6, M7 and M8: $n = 250$; $p = 1$ where n represents the total number of subjects and p represents the total number of parameters. Table 1 shows the variance inflation factor (VIF), logistic regression coefficients, Wald test and odds ratio for the covariates within each model. Employing a 0.05 criterion of statistical significance, all the covariates within each model are found to have significant partial effects. However, odds ratio for RFL is much higher than that for RFB in M1. Similarly, odds ratio for LFL is much higher than that for LFB in M2. This implies that length of a foot is much more effective in determining sex as compared to breadth. On the contrary, breadth of a hand is far more effective in determining gender as compared to length. The odds ratios for right and left foot indices under models M5 and M6 reveal that one unit increase in the index is associated with the odds of males decreasing by a multiplication factor of 0.85, whereas in case of hand indices, it is about 1.5 times more likely to get a man than a woman if the hand index is increased by 1 unit.

The adequacy of the model is tested using two statistics: $-2 \log L$ and Hosmer–Lemeshow. These results along withR^2, sensitivity and specificity for models are shown in Table 2. All the fitted models are adequate as suggested by the values of $-2 \log L$ as well as Hosmer–Lemeshow statistic for which all the corresponding p-values are above 0.10. R^2 values for the first four models are above 0.76 whereas those for the last four models are less than 0.2. Hence models containing individual measurements of length and breadth as covariates are much stronger as compared to corresponding models containing the ratio of length and breadth as a single covariate. With respect to sensitivity and specificity, the percentages of correct classification of males and females for models M1, M2, M3 and M4 are much higher than the counterpart models M5, M6, M7 and M8 respectively.

Table 2
Adequacy and capacity of models.

Model	$-2 \log L$	Hosmer-Lemshow	R^2	Senstivity (%)	Specificity (%)
M1	120.39	5.33	0.79	92	92
M2	125.35	4.60	0.78	91.2	90.4
M3	133.17	11.51	0.77	88	91.2
M4	128.65	10.04	0.78	90.4	91.2
M5	341.05	2.42	0.02	57.6	55.2
M6	338.99	2.29	0.04	56.0	55.2
M7	319.25	8.69	0.14	63.2	68.8
M8	313.35	5.10	0.17	66.4	67.2

The estimates of the probability that the sex is identified as male on the basis of given covariates can be obtained from the fitted equations provided in Table 3.

Our findings suggest that there are significant differences regarding foot as well as hand measurements between men and women of Indo-Mauritian origin. This conclusion is consistent with the findings of Moudgil el al[8] concerning the North-Indian population. However, their study is restricted to foot measurements only. Moreover, we find that although foot and hand indices are significantly different for two genders yet their predictive value is quite low which confirms the findings of Moudgil el al[8] with respect to the foot. It is evident that although all the models are statistically adequate, the models based on foot and hand indices are much weaker in identifying sex as compared to those containing both length and breadth as independent covariates. This fact is justified by lower R-squared values as well as lower percentages of specificity and sensitivity for the models based on indices. Hence, if it is required to identify sex from the right foot, it is recommended to use the model M1 which explains 79% of the variability in response with overall success rate of 92% than the model M5 which explains only 3% of the variability in response with an overall success rate of 56.4%. As an example, if one right foot is available in an investigation which has length of 28 cm and breadth of 11.1 cm then the prediction about the gender of the person corresponding to these foot measurements is done as follows:

Step 1: Choose model M1.

Step 2: Probability (The foot belongs to a male).

$$= \left[1+\exp(57.31-1.93*(28)-1.04*(11.1))^{-1}\right]$$

$$= 0.999$$

Step 3: Since the probability in Step 2 exceeds 0.5, the subject is a male.

In fact, we have used the measurements of the right foot of a male subject and our model M1 is able to make a right prediction with a very high probability. To conclude, our models based on length and breadth of the foot and the hand are capable of predicting sex in the Indo-Mauritian population with fairly high accuracy. Other studies in different parts of the world are required to confirm whether these equations would be equally applicable elsewhere.

Conflict of interest

There is no conflict of interest among authors.

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Ethical approval

None declared.

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